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## **DEVELOPMENT OF A SHIP SERVICE FUEL CELL**

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### **Sommaire**

Sous un programme à trois phases commandité par l'Office of Naval Research (ONR), FuelCell Energy, Inc. est en train de développer une centrale à piles à combustible de 2,5 MW pour la production d'énergie de service du bord à bord des bâtiments de combat de surface. Au cours de la première phase, on a développé un module de design conceptuel de pile à combustible de service du bord (PCSB) et effectué des tests de composants critiques. La deuxième phase qui a été lancée en juin 2000 verra le design en détail, la construction et le test de performance d'un de quatre modules d'énergie de 625 kW qui forment la centrale de PCSB 2,5 MW. Suite aux tests aux installations de FCE à Danbury au Connecticut, le module sera à la U.S. Navy à Philadelphie, en Pennsylvanie pour d'autres tests à terre. Le module d'alimentation sera ensuite testé en mer durant la troisième phase du programme prévue pour 2003-2004.

### **Abstract**

Under a three-phase program sponsored by the Office of Naval Research (ONR), FuelCell Energy, Inc. is developing a 2.5 MW fuel cell power plant for ship service power generation aboard surface combatants. During the first phase, the conceptual design of the ship service fuel cell (SSFC) module was developed and critical component tests were performed. The second phase which was initiated in

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June 2000, will provide detailed design, construction, and performance testing of one of four 625 kW power modules which constitute the 2.5 MW SSFC power plant. Following testing at FCE's facilities in Danbury, CT, the module will be delivered to the U.S. Navy in Philadelphia, PA for additional land-based testing. The power module will then undergo at-sea testing during the third phase of the program scheduled for 2003-2004.

### **Introduction**

Compared to gas turbines and combustion engines, fuel cells possess the potential of superior performance with respect to fuel efficiency and environmental impact. For these reasons, the U.S. Navy is pursuing development of fuel cell power plants for shipboard applications. In 1997, the Office of Naval Research (ONR) initiated a program to demonstrate that commercially developed fuel cell technology can operate on naval fuels in a marine environment. FuelCell Energy, Inc. (FCE) has completed conceptual design and critical components testing for a 2.5 MW Ship Service Fuel Cell (SSFC) power source for future surface combatants, and has commenced construction of a demonstration module for delivery to the U.S. Navy in 2003.

### **DFC® Technology Features**

To meet the 2.5 MW ship service fuel cell (SSFC) requirements, FuelCell Energy, Inc. (FCE) is utilizing its commercial direct carbonate fuel cell (DFC®) technology. This technology is undergoing commercialization for use with natural gas fuel in distributed power generation applications. Because of the internal

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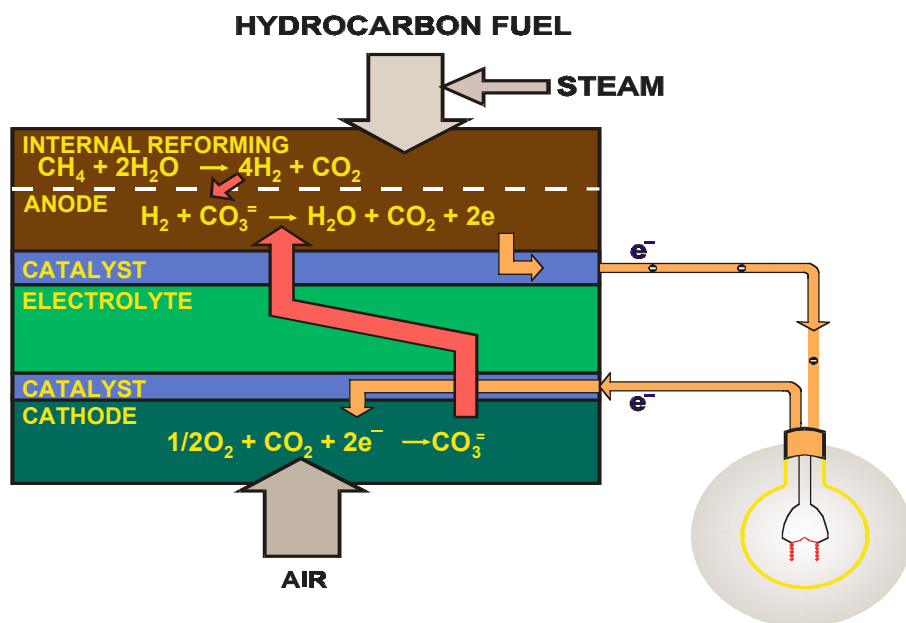
plants based on the DFC® technology will provide thermal efficiency in excess of 50% (LHV).

Carbonate fuel cells have been under development for over 20 years in Europe, Japan, and the United States. At the current time, the principal developer of this technology in the U.S. is FuelCell Energy, Inc. FCE is in the early stages of commercialization of natural gas fueled distributed generators in the power range of 300 to 3,000 kW. Endothermic fuel reforming within the Direct FuelCell (DFC®) utilizes stack waste heat, and therefore the thermal efficiency of the system is improved, the need for external equipment is minimized, and the operating temperature is reduced. This technology has been supported by the U.S. Department of Energy and other funding agencies for over two decades because of its potential to provide clean, efficient power for utilities and independent power generators.

FuelCell (DFC®) is the most advanced fuel cell system for marine and other applications. A 2 MW natural gas DFC® was built and operated by FCE (formerly Energy Research Corp.) in California between 1995 and 1997 to generate local utility power. This DFC® power plant set records for fuel adjustment efficiency, low sulfur and nitrogen oxide emissions, and low noise levels in comparison with similar size conventional power plants. Extensive government and private funding continues to support FCE's development of DFC® power plants for commercial introduction by the year 2001. This development work assures continued availability of a commercially based fuel cell stack and fuel cell technology for utilization by the Navy and in other marine applications.

#### Operating Principles of DFC® Technology

The operating principles of the direct carbonate fuel cell are illustrated in Figure 1. The schematic cross-sectional view of a fuel cell shows the internal reforming and power producing reactions.



Because of the high efficiency and ability to operate directly on hydrocarbon fuels, the Direct

**Figure 1.**

#### **Direct Fuel Cell Reactions**

*Thermal integration within the cell produces high system efficiency*

Methane mixed with steam is converted to hydrogen and carbon dioxide over reforming catalyst present within the anode flow field of the cell. The power producing anode reaction converts the hydrogen to steam which allows the reforming to go to completion at the relatively low operating temperature of 650°C by continuously shifting the equilibrium of the reaction toward completion. The endothermic reforming reaction serves to remove the waste heat from the stack. This integration of the fuel cell and reforming reactions is the principal reason for the uniquely high efficiency of the DFC® system.

On the cathode side, oxygen and carbon dioxide are reduced to carbonate ions and provide electric current conduction through the potassium-lithium carbonate electrolyte.

The fuel cells are stacked to produce the required power and output voltage. Typically, about 350 cells are stacked for commercial power plants. A stack assembly of cells measuring about 1.2 m x 0.6 m can be seen in Figure 2.



**Figure 2.**

**A Commercial DFC® Stack**

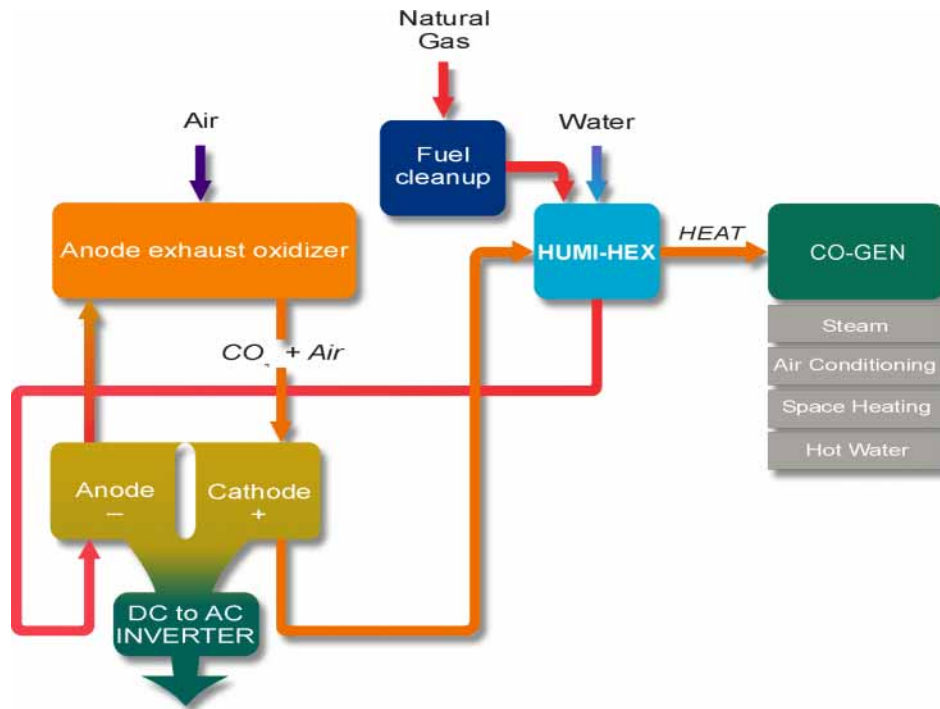
*Cells are stacked to provide the required power output*

fuel is treated to remove impurities, mixed with steam and sent to the fuel cell stacks. The hydrocarbon fuel is reformed in the stacks providing the hydrogen, which is consumed in the fuel cell anodes. The residual fuel in the anode exhaust is oxidized with excess air in a catalytic reactor and produces the cathode feed stream. The steam required for internal reforming of the fuel is generated with fuel cell stack exhaust heat.

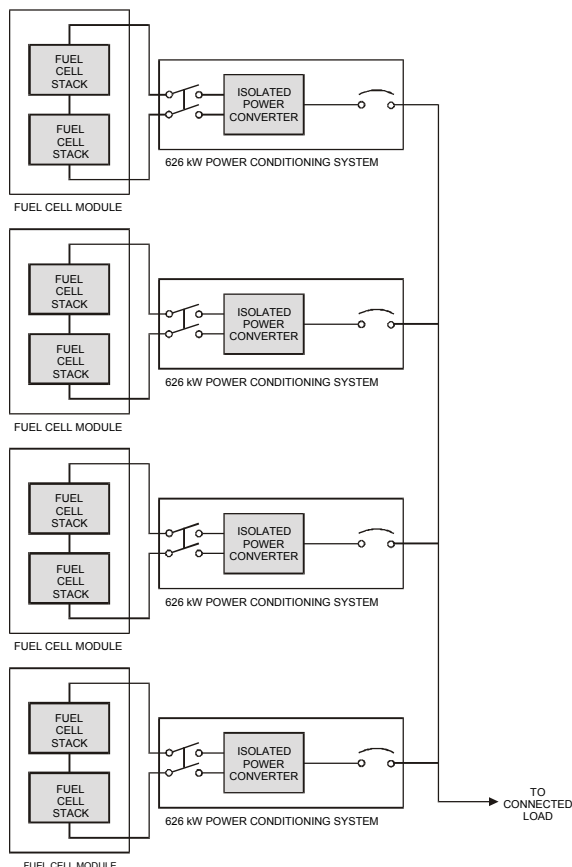
**2500 kW SSFC Design**

The design concept for the 2500 kW SSFC incorporates four independent 625 kW power modules delivering power in parallel to the ship service 450 volt bus as shown in Figure 4. Each module is built with two fuel cell stacks of direct carbonate fuel cells connected in series and providing 450-700 volts DC to the power conditioning system which converts the DC stack output to AC power. A simplified process flow diagram for the independent 625 kW module is shown in Figure 5. The fuel processing system first desulfurizes the NATO F-76 fuel by hydrodesulfurization (HDS) followed by absorption in a zinc oxide (ZnO) bed, and then converts it adiabatically to a methane-rich gas useable in the fuel cell anode. The required steam is generated utilizing waste heat from the fuel cell cathode exhaust. The water needed for steam generation is condensed from the fuel cell anode exhaust stream.

The equipment in each of the independent 625 kW power plant modules is housed within its own enclosure, which provides a closed environment for safety and attenuation of noise from the ancillary equipment in the system. Each 625 kW module contains fuel cell stack power conditioning equipment, a fuel processor, thermal management and controls making it a completely autonomous power source.



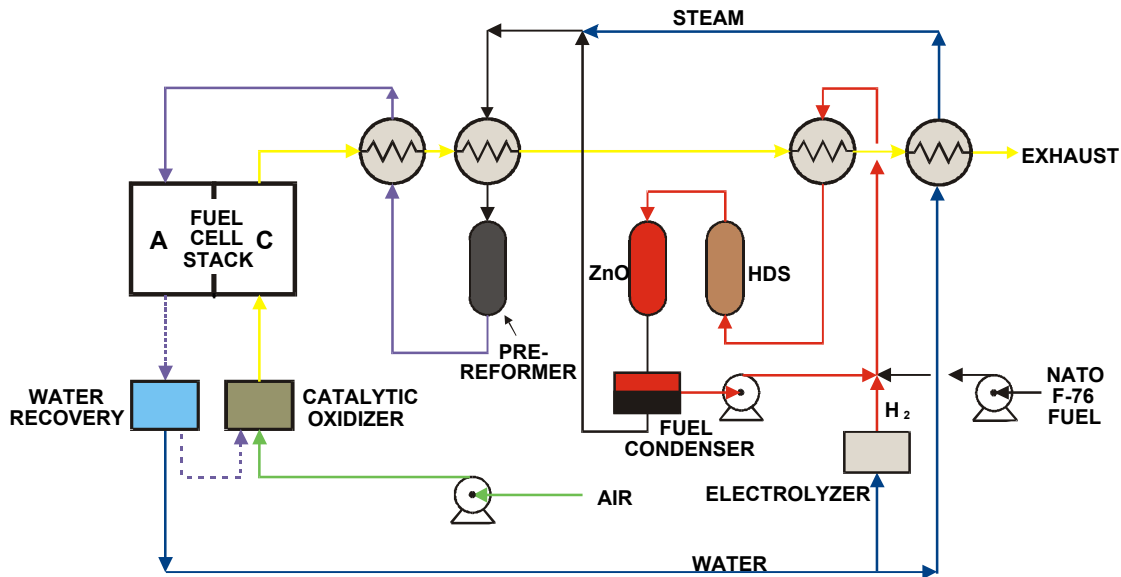
**Figure 3.**  
**Simplified Natural Gas System Schematic**  
*Hydrocarbon fuel is reformed in the fuel cell anode*



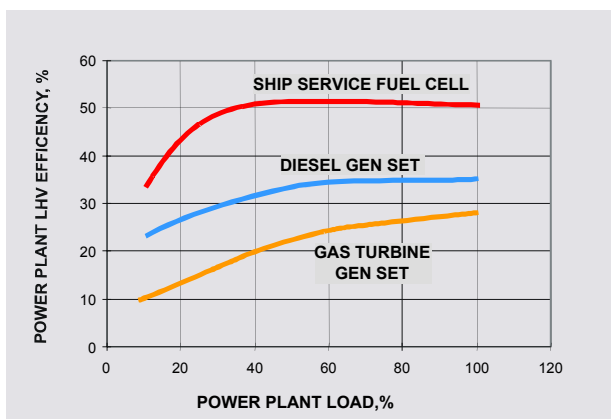
**Figure 4**  
**2.5 MW SSFC Power Plant Electrical Configuration**

The projected efficiency of the SSFC power plant over the range of power plant load is shown in Figure 6. The efficiency of a power plant which uses direct carbonate fuel cells is exceptionally high because all the energy required in the fuel conversion process is provided by the waste heat generated in the fuel cells. The efficiency of a commercial 2500 kW gas turbine generator set at ISO conditions and medium speed diesel genset efficiencies are shown for comparison. At higher ambient temperatures, the gas turbine generator efficiency declines significantly, while the SSFC does not. Relative pollutant generation for the three power sources when operating on natural gas is compared in Figure 7. Pollution from the fuel cell can be seen to be negligible.

A conceptual equipment arrangement for the 625 kW power module is shown in Figure 8.



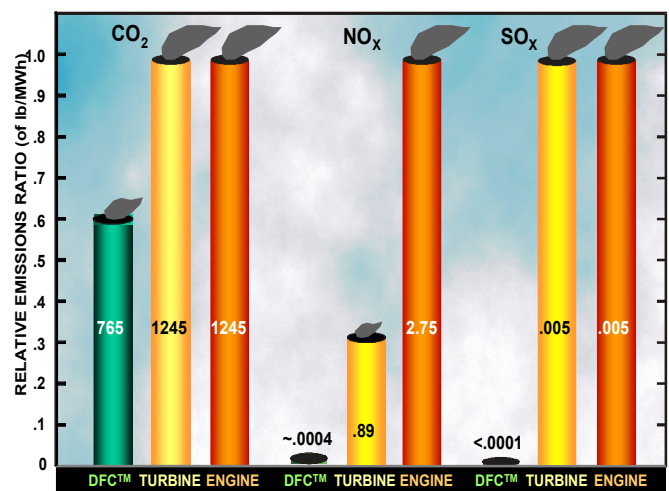
**Figure 5.**  
**SSFC Power Plant Process Flow Diagram**  
*Marine fuel is converted to methane for use in the DFC® stack*



**Figure 6.**  
**Efficiency vs. Load Comparison for Fuel Cell and Gas Turbines**  
*Fuel cell generator is efficient over a wide load range*

#### **Other Marine DFC® Applications**

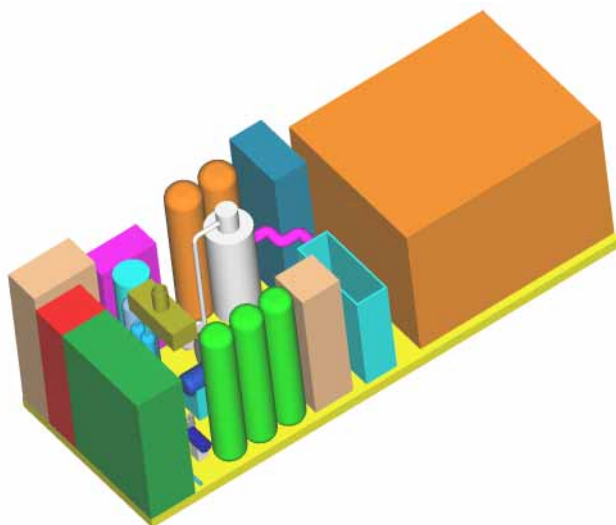
The marine carbonate fuel cell development for the U.S. Navy is leveraged by FCE's stationary fuel cell power plant development for distributed power generation. FCE believes that the combined available U.S. and European market for distributed power generation will reach 7,600 MW/year by 2004. The company's fuel cell products can potentially address a 25GW commercial and industrial



**Figure 7.**  
**Emission Comparison of Natural Gas Fueled Distributed Generators**  
*Fuel cell pollutant emissions are negligible compared to conventional generators*

power market in the U.S., which is about 3% of total U.S. generating capacity. This represents about 24,000 power plants in the 0.3 to 3 MW power range. By comparison, the demand for ship service generators in the 0.5 to 2.5 MW power range is projected to be over 6,000 units in the 2001 to 2005 time period.

There is also a very large market potential for fuel cell electrical generating plants for



**Figure 8.**  
**625 kW Module Internal Arrangement**  
*All equipment is skid-mounted*

commercial ships around the world, which far exceeds the currently estimated 5 GW U.S. Naval auxiliary power requirement for the 1990-2020 period. A potential early market for logistic fuel DFC<sup>®</sup> power units appears to be in the cruise ship industry. Currently, this industry is undergoing changes in ship design as well as operating philosophy with emphasis on environmental as well as fuel efficiency benefits. The industry is also moving toward all electric ships, which makes application of fuel cells for ship service as well as for propulsion more attractive. The principal drivers for fuel cell use will be better fuel economy, clean exhaust, and negligible noise and vibration. These benefits can translate to better space utilization for passengers, while eliminating emissions and reducing overall ship power generation operating costs.

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